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CONTROLLED ATMOSPHERE EFFECTS ON LETTUCE QUALITY IN SIMULATED EXPORT SHIPMENTS

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CONTROLLED ATMOSPHERE EFFECTS ON LETTUCE QUALITY IN SIMULATED EXPORT SHIPMENTS

1928—
258

By

Werner J. Lipton,[1] plant physiologist,
Market Quality Research Division, Agricultural Research Service

SUMMARY

The market quality of head lettuce was evaluated after storage for 1 month at 36.5° or 41° F. in atmospheres containing 21 or 3 percent oxygen (O_2) combined with 0, 2, or 4 percent carbon dioxide (CO_2). Market quality was again evaluated after an additional 3 days in air at 50°. Some of the lettuce was stored with wrapper leaves and some without. These variables simulated conditions encountered during transportation overseas.

Carbon dioxide injured the lettuce in three of the four tests. The principal symptoms of injury were dead heart leaves and brown stain. Low O_2 increased the sensitivity of lettuce to high CO_2 injury.

Controlled atmospheres (CA) reduced decay, particularly when low O_2 and high CO_2 were combined. However, removal of all wrapper leaves before storage reduced decay nearly as much as CA.

Pink rib was inhibited by high CO_2 at both O_2 concentrations, but low O_2 tended to increase pink rib regardless of CO_2 concentration.

Yield of edible lettuce was higher after storage in CA than in air, but only lettuce stored at 36.5° F. was considered salable after 1 month, regardless of storage atmosphere.

When the danger of injury from high CO_2 or low O_2 is balanced with the benefits of significant reductions in decay and pink rib, CA can be advantageous for storage periods of about 1 month, or possibly longer. A combination of 3 percent O_2 with 2 percent CO_2 seems optimal. However, even with CA, temperatures must be 36° F. or lower if a reasonable amount of salable, or even edible, lettuce is to be recovered at destination.

BACKGROUND

Effects of controlled atmospheres (CA) on the market quality of head lettuce have been evaluated during actual (6)[2] and simulated (2, 7, 9) shipping tests of about 1 week's duration. However, the effects of CA during longer times, as in overseas shipments, have been tested only with respect to oxygen (O_2) and at one temperature (4). The volume of exported lettuce in 1968 amounted to nearly 5 million pounds (8), more than double the volume in 1967. Therefore, testing its response to prolonged exposure to low O_2 and high carbon dioxide (CO_2) for various storage periods (2) seemed advisable. The market quality of lettuce was evaluated after storage for 1 month in several combinations of O_2 and CO_2, at a satisfactory temperature and at a somewhat higher than desirable "transit" temperature. The relative merits of storing lettuce with or without wrapper leaves also were evaluated.

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[1] 2021 S. Peach, Fresno, Calif. 93727

[2] Underscored numbers in parentheses refer to Literature Cited at end of the report.

METHODS

Sources of Test Lettuce

Lettuce of the Great Lakes type was obtained in 1969 from the Salinas (June and August) and San Joaquin Valleys (October), and in 1970 from the Imperial Valley (January), Calif. The lettuce for the first three tests was cut and packed by field crews, but to reduce injury, only 18 heads were placed in each carton, instead of the customary 24. Lettuce from the Salinas Valley was vacuum cooled within 1 hour after harvest, after which it was transported under refrigeration to the U.S. Department of Agriculture laboratory at Fresno, Calif. Lettuce from the San Joaquin Valley was not vacuum cooled because of the short transit period from the field to laboratory. The lettuce from the Imperial Valley was commercially handled and purchased from a local wholesaler the day after harvest.

Storage Environment and Condition of Lettuce During Holding

The lettuce was placed in stainless steel chambers and exposed to the chosen atmosphere starting the day of harvest or the day after harvest. Each chamber contained heads from each original carton, totaling 14, 15, or 16 heads, depending on their size in a given test. Adjacent heads were from different cartons to reduce the chance of having undetected decay of field origin concentrated in one chamber. Wet paper towels maintained a high relative humidity in the chambers.

After closure, the chambers with low O_2 were flushed with nitrogen (N_2) to rapidly reduce the O_2 level. The storage atmospheres contained the following concentrations of gases: 21 or 3 percent O_2, each with 0, 2, or 4 percent CO_2, with N_2 constituting the remainder. There were two chambers per treatment or a total of 12 chambers for each test.

The atmospheres were maintained by a continuous flow of the appropriate gas mixture from high-pressure cylinders. Chambers used as controls were flushed continuously with air. The rate of flow (300 ± 50 ml. per minute) was sufficient to keep all effluent gases at the desired concentrations, when monitored with an Orsat gas analyzer. The predetermined atmospheres were reached in less than 24 hours after closing the chambers.

Two tests each were run at 36.5° and at 41° F. (2.5° and 5.0° C. ± 0.3°, respectively). The lettuce was stored with wrapper leaves attached in one test at each temperature and without wrapper leaves in the remaining tests.

Evaluation of Market Quality

Half the lettuce in each lot was examined after 1 month in air or in the controlled atmospheres (simulated overseas transit period), and the remainder after an additional 3 days in air at 50° F. (10° C.) (simulated wholesale-retail period). Each head was rated for decay, pink rib, russet spotting, and CO_2 injury on a scale of 1 to 9 (1 = defect absent, 3 = trace, 5 = slight, 7 = moderate, 9 = severe). The severity ratings given in the text or tables are the means only of those heads rated 3 or higher. Thus the means show how severely heads were affected and are not diluted by ratings of 1 given to sound heads. Data on the incidence of each disorder are shown separately.

An index expressing the seriousness of decay and pink rib from the receiver's or consumer's point of view was calculated by multiplying percent incidence by the corresponding severity rating and dividing the product by 100. This index gives a better overall idea of the seriousness of a given disorder than either rating alone, because a high incidence of a defect rated "3" (trace) may be less objectionable than a lower incidence of one rated "7" (moderate). However, no given index number divides acceptable from unacceptable lots, because a sample with a mean decay index of 3.0 probably is less acceptable than one with a mean pink rib index of 4.5.

The general appearance of heads with and without wrapper leaves was rated on a scale from 9 to 1 (9 = field fresh, no defects; 7 = good, minor defects; 5 = fair, objectionable defects can be corrected before sale; 3 = poor, generally unsalable; 1 = inedible).

The percentage of edible lettuce remaining at each examination was determined by weighing each lot when removed from storage and again after all inedible parts were trimmed off. Wrapper leaves were removed before any weighing. Inedible parts included those that were decayed or sufficiently discolored to preclude their use in a salad, and also included the stem, regardless of condition.

Appropriate data were evaluated by analysis of variance for a split-split plot design and the means were compared with Duncan's Multiple Range test. Absence of decay in some tests precluded statistical evaluation of its incidence or severity. Data on CO_2 injury also were excluded from statistical analysis, because the point of interest is not whether the extent of injury under different atmospheres differs significantly, but whether injury occurred at all, and if it did, whether it was objectionable.

RESULTS

Injurious Effects of CO_2

Carbon dioxide injured the lettuce in three of the four tests. The extent of the injury depended on CO_2 and O_2 concentrations in the controlled atmosphere (table 1). Generally, 4 percent CO_2 caused more widespread and more severe injury than 2 percent CO_2. Symptoms of injury were dead heart leaves and distinct tan to brown surface lesions scattered over the midribs. These surface lesions have been termed brown stain (7) and may be identical to injuries attributed to high CO_2 by Hill (1).

Dead heart leaves were found in about five times as many heads stored in 4 percent CO_2 as in those stored in 2 percent CO_2 (56 percent vs. 11 percent of heads were affected). Brown stain was nearly twice as common at the higher CO_2 level (32 percent vs. 19 percent of heads were affected). Neither type of CO_2 injury increased consistently during the simulated wholesale-retail period in air. Because individual heads of lettuce respond differently to CO_2, sometimes fewer heads appeared injured at the second than at the first examination. When lettuce has been stored for 1 month in CA, the symptoms of CO_2 injury are fully expressed and there is little further injury during holding in air. This contrasts with short-term CA storage, where the symptoms increase in severity during subsequent holding in air (7).

Injury to the heart leaves depended on the maturity of the heads in the January 1970 test, in which 67 percent of soft heads had dead heart leaves, but only 56 percent of firm heads were similarly affected. Further, the injury tended to be more severe in the soft than in the firm heads. Finally, dead margins were evident on green, inner head leaves in 59 percent of soft heads with dead heart leaves, but in only 15 percent of the firm heads. Injury to heart leaves did not depend on maturity in any other test.

The sensitivity of the youngest tissue in a head to CO_2 injury is similar to the occurrence of low O_2 injury (2), in which the tissue surrounding the growing point also was the first to be damaged. The only exception to these observations was the June 1969 test in which the incidence of dead heart leaves was rather low, compared with that of brown stain.

High CO_2 seemed to induce another disorder of the midribs, but only in the October 1969 test. In this test, 14 heads held in 2 or 4 percent CO_2 had midribs that were yellow to reddish tan. The discoloration also spread into adjacent tissue and affected broad areas rather than distinct lesions, as noted for brown stain. Yellow predominated immediately after CA storage, but the color changed and darkened during subsequent holding in air.

Low O_2 atmospheres increased the susceptibility of lettuce to high CO_2 injury, as also noted by Stewart and Uota (7). Thus, the incidence and severity of brown stain were greater in lettuce stored in 3 percent than in 21 percent O_2 when either was combined with 2 or 4 percent CO_2. Three percent O_2 had no effect on CO_2 injury to the heart leaves.

Table 1.--Types, incidence, and severity of CO_2 injury to lettuce stored in various concentrations of O_2 and CO_2

Harvest date1/ and storage condition2/	Heads with dead heart leaves when stored in indicated atmosphere				Heads with brown stain when stored in indicated atmosphere				Severity ratings of brown stain of heads			
	Atmosphere3/ No.--				Atmosphere3/ No.--				Atmosphere3/ No.--			
	1	2	3	4	1	2	3	4	1	2	3	4
	-----Percent4/----				----Percent4/----				-----Number5/----			
June 1969:												
1 month 36.5° F.--CA--	0	14	0	29	31	59	62	93	5.5	6.5	5.6	6.9
Plus 3 days 50°--air--	0	21	0	7	28	69	93	86	3.6	4.9	6.1	8.0
October 1969:												
1 month 41° F.--CA----	6	37	6	56	0	12	0	6	---	4.0	---	3.0
Plus 3 days 50°--air--	12	69	12	81	0	0	6	0	---	---	5.0	---
January 1970:												
1 month 36.5° F.--CA--	24	93	24	100	0	0	0	12	---	---	---	4.0
Plus 3 days 50°--air--	24	100	25	93	0	0	6	56	---	---	---	3.8
Means------------------	11	56	11	61	10	23	28	42	---	---	3.0	---

1/ The harvest of August 1969 is omitted because no CO_2 injury occurred in any atmosphere.

2/ CA refers to storage in one of the controlled atmospheres given in footnote 3.

3/ Atmosphere 1 21 percent O_2, 2 percent CO_2; atmosphere 2 21 percent O_2, 4 percent CO_2; atmosphere 3 3 percent O_2, 2 percent CO_2; atmosphere 4 3 percent O_2, 4 percent CO_2.

4/ The percentages are based on 14, 15, or 16 heads.

5/ Rating scale: 1.0 = none; 3.0 = trace; 5.0 = slight; 7.0 = moderate; 9.0 = severe. Ratings are means of affected heads only. Dashes indicate lots without brown stain.

General Effects on Quality

Decay.--Incidence of decay (mostly bacterial soft rot) depended more on the presence or absence of wrapper leaves and on storage temperature than on storage atmosphere.

When the wrapper leaves were left on the heads, nearly all heads showed some decay at both storage temperatures, in all six atmospheres, and at both examinations. When wrapper leaves were removed, the lettuce was nearly free of decay at both examinations after prior storage at 36.5° F., regardless of any other variable. However, when held at 41°, decay was common in all atmospheres, except 3 percent O_2 with 4 percent CO_2 (table 2). The data at both examinations indicate, therefore, that high CO_2 had little effect on decay when combined with normal O_2, but that it usually was effective in reducing decay when combined with low O_2. Low O_2 atmospheres without CO_2 about halved the incidence of decay during CA storage, but had no residual effect at the second examination (table 2).

Severity of decay at 41° F. essentially followed the pattern for incidence of decay (table 2).

The decay index, which represents the overall seriousness of spoilage, emphasizes the reduction in decay achieved by high CO_2 and low O_2 during CA storage (table 2). The index also shows that some of the benefits of high CO_2 with 21 percent O_2 were lost when the lettuce was transferred to 50° for the three-day holding period in air. However, the benefits of CO_2 persisted for those lots originally held in 3 percent O_2.

Pink rib.--Pink rib was present in most heads in all treatments, although high CO_2 atmospheres reduced its incidence somewhat, particularly when combined with low O_2 (table 3). Four percent CO_2 reduced the severity of pink rib when combined with 21 percent O_2 but not when combined with 3 percent O_2. In fact, low O_2 tended to enhance pink rib at a given CO_2 concentration, although the differences were not statistically significant (table 3). Finally, the index shows that CO_2 inhibits pink rib at normal and low O_2 concentrations, and also suggests that low O_2 can aggravate the disorder (table 3).

Temperature did not influence the incidence of pink rib consistently; severity, however, was greater in lettuce held at 41° F. than in that held at 36.5°. The respective severity ratings, 6.9 and 4.3, differ at the 99 percent probability level. Also, the pink rib index after CA storage was 6.5 at 41° and 2.4 at 36.5°, with the difference significant at the 99 percent probability level. The same trend existed after the 3 additional days in air at 50°, but the indices (7.1 and 3.7, respectively) did not differ significantly.

Russet spotting.--The incidence of this disorder was negligible in all four tests.

Table 2.--Decay incidence, severity, and index for lettuce stored without wrapper leaves in various concentrations of O_2 and CO_2

Storage condition	O_2 concentration	Incidence of decay in indicated percentage of CO_2			Severity rating of decay in indicated percentage of CO_2			Index of decay in indicated percentage of CO_2		
		0	2	4	0	2	4	0	2	4
	Percent	----Percent-----			---Number[1]---			---Number[2]---		
1 month at 41° F.---	21	75	37	68	6.1	5.3	4.8	4.5	2.1	3.3
Do-----------	3	37	49	0	3.6	3.0	---	1.4	1.7	0
Plus 3 days at 50° in air-----------	21	68	87	62	5.6	5.0	5.6	4.0	4.3	3.3
Do-----------	3	75	31	31	5.3	5.6	4.0	4.0	1.4	1.2

[1] Ratings are means of affected heads only. Rating scale: 3 = trace; 5 = slight; 7 = moderate; 9 severe.

[2] Percent incidence x severity rating ÷ 100. The values are means calculated from individual lots and, therefore, do not necessarily correspond to the product of the corresponding tabular values.

Table 3.--Pink rib incidence, severity, and index for lettuce stored in various concentrations of O_2 and CO_2[1]

O_2 concentration, percent	Incidence of pink rib in indicated percentage of CO_2			Severity of pink rib in indicated percentage of CO_2			Index of pink rib in indicated percentage of CO_2		
	0	2	4	0	2	4	0	2	4
	-----Percent[3]-----			---Number[3],[4]----			Number[2],[3]		
21	94 b	84ab	75a	5.9 bc	5.3ab	4.6a	5.6 cd	4.5ab	3.7a
3	90 b	73a	77a	6.6 c	5.5abc	5.7abc	6.2 d	4.7 bc	4.8 bc

[1] The data are overall means of lots held with or without wrapper leaves for 1 month at 36.5° or 41° F., plus 3 days in air at 50°.

[2] Percent incidence x severity rating ÷ 100. The values are means calculated from individual lots, therefore, they do not necessarily correspond to the product of the corresponding tabular values.

[3] Means having no letter in common differ at the 95 percent probability level.

[4] Rating scale: 1.0 = none; 3.0 = trace; 5.0 = slight; 7.0 = moderate; 9.0 = severe. Ratings are means of affected heads only.

Quality Ratings of Lettuce with Wrapper Leaves Attached

Controlled atmospheres had little influence on quality ratings of lettuce stored with wrapper leaves attached (table 4), because CA did not substantially reduce decay in such lots. However, lettuce held at 36.5° F. in any controlled atmosphere was superior to that stored in air when examined after holding for 3 days at 50°. All lettuce stored at 36.5° was superior to that stored at 41°, and in the latter only certain modified atmospheres resulted in better quality than lettuce held in air, and only at the first examination (table 4).

Table 4.--Quality ratings of lettuce with wrapper leaves attached and stored in various concentrations of O_2 and CO_2

Storage condition	O_2 concentration	Quality ratings[1/][2/] of lettuce stored in indicated percentage of CO_2		
		0	2	4
	Percent	- - - - - - - -Number- - - - - - - - - -		
1 month at 36.5° F. -	21	5.2a	6.1a	5.3a
Do - - - - - - - -	3	5.8a	6.2a	5.5a
Plus 3 days at 50° in air - - - - - - - - -	21	3.1a	4.4 b	4.9 b
Do - - - - - - - -	3	4.3 b	5.1 b	4.3 b
1 month at 41° F. - -	21	1.0a	1.3a	2.8 b
Do - - - - - - - -	3	1.8a	2.7 b	3.0 b
Plus 3 days at 50° in air - - - - - - - - -	21	1.0a	1.1a	1.3a
Do - - - - - - - -	3	1.0a	1.1a	1.7a

[1/] 9 = excellent; 7 = good; 5 = fair; 3 = unsalable; 1 = inedible.

[2/] Means for a given temperature and period (6 values) without a letter in common differ at P 95 percent.

Quality Ratings of Lettuce with Wrapper Leaves Removed

Controlled atmosphere storage did not significantly influence the quality ratings of lettuce stored without wrapper leaves, or of lettuce stored with wrapper leaves and evaluated after the leaves were removed. In this case there was no difference, because lots with much decay had less CO_2 injury, and those with much CO_2 injury had less decay.

Storage temperature, however, greatly influenced these quality ratings, as was expected. Lettuce stored at 36.5° F. was rated better than fair (5.8) at the first examination, whereas that stored at 41° was judged to be unsalable (2.4). After the additional 3 days at 50°, the respective quality ratings were 4.5 and 1.4.

Yield of Edible Lettuce

The yield of edible lettuce remaining at termination of storage is a meaningful criterion for judging the value of CA storage when usability rather than salability is important. When usability is important, appeal of the entire head is disregarded. Consideration is given only to the portion remaining after all inedible parts have been removed.

The effect of CA storage on yield of edible lettuce was shown most clearly for lots stored at 41° F. with wrapper leaves attached (table 5). Carbon dioxide was beneficial regardless of O_2 concentration, but low O_2 resulted in a higher yield than normal O_2 when combined with either 0 percent or 2 percent CO_2. At 36.5°, a more desirable transit temperature, CA conditions had no significant effect on the yield of edible lettuce.

When all tests, regardless of temperature or presence of wrapper leaves, are considered, the relative ranking of the various atmospheres in respect to yield of edible lettuce remained as in table 5. However, the values ranged from 61 percent for air to 75 percent for the combination of 2 percent CO_2 with 3 percent O_2.

Storage temperature naturally influenced the yield of edible lettuce. After storage at 36.5° F., and disregarding the effect of CA treatments or wrapper leaves, 89 percent of the lettuce was edible; after the additional wholesale-retail period, the yield was 84 percent. The respective values for lots stored at 41° were 60 and 50 percent.

Table 5.--Yield of edible lettuce in heads with wrapper leaves attached and stored in various concentrations of O_2 and CO_2

O_2 concentration	Yield of edible lettuce after storage in indicated percentage of CO_2		
	0	2	4
Percent		Percent[1]	
21	14a	43 b	58 c
3	37 b	57 c	57 c

[1] The data are overall means for lettuce examined after 1 month at 41° F. in the atmospheres given, and after 3 additional days in air at 50°.

Means without a letter in common differ at the 95 percent probability level.

DISCUSSION

Lettuce stored at an unfavorably high temperature (41° F.) for 1 month benefitted more from CA storage than lettuce stored at a lower temperature (36.5° F.), because the greater amount of deterioration at 41° F. permits beneficial effects to show up more readily. This result is similar to that for lettuce stored only 1 week (2). Thus, even though the reduction in waste attributable to CA was greater at 41° than at 36.5°, more edible lettuce remained at the lower temperature. For example, at 36.5°, 84 percent edible product remained after 1 month in air, but at 41°, the best CA treatment (3 percent O_2 with 4 percent CO_2) yielded only 71 percent edible lettuce. However, since lettuce commonly is exposed to temperatures above 36.5° during transit (5), supplementing refrigeration with CA would contribute to a maximum yield of edible product. This maximum might be lower after actual shipment, however, than under these simulated conditions, because of additional physical handling, which would increase damage.

The yield of edible product must be carefully distinguished from yield of salable product. With a rating of 3 indicating "unsalable," only lettuce stored at 36.5° F. was salable at either examination, regardless of atmosphere composition (table 4). All lettuce stored at 41° had deteriorated so much, mainly because of decay, that it would have been rejected for commercial use. Thus, for long transit periods temperatures as close to 32° as feasible and safe are essential even when CA is used. For conditions where desirable temperatures cannot be maintained throughout transit, CA assumes equal importance with removal of wrapper leaves and low temperatures if more than a token amount of edible lettuce is expected at destination.

The chief benefit of CA storage is the reduction in decay and pink rib, which, in these tests, more than compensated for injuries induced by 2 or 4 percent CO_2.

Both low O_2 and high CO_2 inhibit decay. The effects of high CO_2 continue through a holding period in air at 50° and are evident in the decay index (table 2). This effect of high CO_2 and low O_2 was undetectable after brief storage (7), and confirms an earlier suggestion that low O_2 (2) may help check decay during prolonged storage, even though its effect is negligible during short periods.

While CA reduced decay in lettuce stored without wrapper leaves, it was less effective on lettuce stored with wrapper leaves attached. When stored in this manner, nearly all heads showed some decay regardless of storage atmosphere. Consequently, all wrapper leaves should be removed if lettuce is to be stored 1 month or more in CA or in air. This finding parallels results reported earlier (3).

Pink rib was reduced in atmospheres with added CO_2. Low oxygen either exerted no effect, or slightly aggravated the disorder, particularly its severity. Thus, the results for 1 month's and 1 week's storage are parallel in respect to effects of O_2 (2) on pink rib, but not in respect to CO_2, which had no effect on pink rib during the shorter period (7).

Russet spotting is reduced substantially by low O_2 atmospheres (2, 5) during short storage or transit periods, but the effectiveness of low O_2 on this disorder during prolonged storage could not be evaluated because of the extremely low incidence of russet spotting in all four tests.

The sporadic occurrence of CO_2 injury, also noted by Stewart and Uota (7), cannot be explained on the basis of the present data or those given in the earlier report. However, the close control of storage conditions suggests that susceptibility of lettuce to CO_2 injury may be affected by an unknown variable that exerts its influence before storage.

The reductions in decay and pink rib achieved by elevated CO_2 levels in these tests indicate that recommendations for short storage periods are not necessarily valid for prolonged periods. For short periods, the danger of injury from even 2 percent CO_2 outweighs any possible advantage (7), whereas, during one month's storage, the reverse is true.

CONCLUSIONS

If lettuce is to be stored for 1 month, or even longer, all wrapper leaves should be removed before packing and temperatures should be maintained as low as feasible and safe, preferably below 36° F. Controlled atmospheres also are useful, particularly when temperatures are expected to be higher than ideal. Finally, trimmed lettuce must be held in high relative humidity or wilting will occur (3). If CA is used, a combination of 3 percent O_2 with 2 percent CO_2 is recommended because it reasonably balances the danger of injury from excessively low O_2 or high CO_2 with the benefits of reduction in decay and pink rib. In no event should the atmosphere be maintained with O_2 below 1 percent or CO_2 appreciably above 2 percent.

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